HYBRID RF AND OPTICAL WIRELESS COMMUNICATION LINK AND NETWORK STRUCTURE INCORPORATING IT THEREIN

TECHNICAL FIELD

The present invention relates to broadband communication systems, and more particularly to wireless communication links within broadband networks.

BACKGROUND

Gigabit data transport and processing technologies are required to respond to the needs of present and future information distribution and high-speed Internet applications. Fiber optics technology has matured as a method of data transport, allowing information exchange rates at terabit levels, and potentially beyond. However, in areas lacking fiber infrastructure, wireless technologies employing radio frequency and free-space laser links are the medium of choice for broadband wireless networking. In the wireless domain, and particularly in radio frequencies, propagation effects, atmospheric degradation, and environmental factors limit the maximum communication channel speed/data rates, link performance, and availability.

Typical bit rates for radio frequency systems are in the range of a few megabits per second for mobile applications and in the range of a few hundred megabits per second for fixed wireless links. Even at these relatively low data rates, the links typically suffer from high error rates and low quality of service performance, both typically several orders of magnitude worse than with fiber optics.

In particular, wireless optical links suffer degradation due to fog and other atmospheric conditions that severely attenuate the wireless signal and block the transmission of light from link to link, while radio frequency links suffer degradation due to rain and other particulate matter between links, as well as multipath effects caused by signal reflection.

Therefore, it would be desirable to provide a communication link system incorporating a hybrid mixture of optical and radio frequency links to provide communication link redundancy, to cope with signal degradation, and to mitigate the particular atmospheric limitations of each.

SUMMARY

The present invention provides, in one embodiment, a node incorporating hybrid radio frequency and optical wireless communication links, wherein the node comprises a laser portion for transmitting data; a radio frequency portion for transmitting data; a data receiver for receiving data from a data source; and a controller configured to receive data from a data source and connected with the laser portion and the radio frequency portion to allocate the portions of the data to be transmitted through the laser portion and the radio frequency portion.

In another embodiment, the node further incorporates a controller that is configured as a binary switch such that the data is transmitted exclusively through either one of the laser portion and the radio frequency portion.

In yet another embodiment, the node incorporates a controller configured to receive environmental information, and the controller based on the environmental information adjusts the portions of the data to be transmitted through the laser portion and the radio frequency portion.

In still another embodiment, the laser portion is configured to both transmit and receive and the radio frequency portion is configured to both transmit and receive.

In another embodiment, the laser portion and the radio frequency portion are configured to transmit in multiple channels.

In a further embodiment, the the controller is configured to monitor the transmit and receive strengths, wherein the portions of the data to be transmitted through the laser portion and the radio frequency portion are adjusted by the controller based on their transmit and receive strengths.

In yet another embodiment, the controller includes a plurality of latches and a logic device, where the plurality of latches and the logic device operate to provide adjustment levels for the portions of the data to be transmitted through the laser portion and the radio frequency portion. Thus, the overall bandwidth of the hybrid radio frequency and optical wireless communication link may be optimized for a particular set of weather conditions.

In a still further embodiment of the present invention, the laser portion and the radio frequency portion have aggregate transmit and receive strengths, and the controller is configured to monitor the aggregate transmit and receive strengths, wherein the portions of the data to be transmitted through the laser portion and the radio frequency portion are adjusted by the controller based on their transmit and receive strengths.

In another embodiment of the present invention, each transmission channel has a transmit and receive strength, and wherein the controller is configured to monitor the transmit and receive strength of each channel; and the channels of the data to be transmitted through the laser portion and the radio frequency portion are determined by the controller based on their transmit and receive strengths.

In yet another embodiment of the present invention, the laser portion and the radio frequency portion are configured to transmit and receive in tandem, so that the node may be configured to provide a hybrid serial link to permit tailored radio frequency or optical network connections.

In a further embodiment of the present invention, an optical reflector is used to deflect transmissions from the laser portion in order to work around fixed objects in the environment, so that the node may be used to extend a network and the laser portion can maintain communication without the need for a strict line-of-site connection.

In another embodiment of the present invention, a network is presented, incorporating hybrid radio frequency and optical wireless communication links, with the network comprising a plurality of nodes, with each node including a laser portion for transmitting data; a radio frequency portion for transmitting data; a data receiver for receiving data from a data source; and a controller configured to receive data from a data source and connected with the laser portion and the radio frequency portion to allocate the portions of the data to be transmitted through the laser portion and the radio frequency portion. Each node in the network may be configured in any of the embodiments previously discussed.

In a further embodiment of the network, at least a portion of the network may be configured as a ring topology, and more specifically as a SONET ring.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1(a) is a block diagram showing an embodiment of the hybrid wireless link of the present invention with a laser portion, a radio frequency portion, and a controller;

FIG. 1(b) is a block diagram showing several modes of operation of the laser portion and the radio frequency portion of an embodiment of the hybrid wireless link of the present invention, wherein the hybrid wireless link includes a binary switch in the controller;

FIG. 2 is a block diagram showing a multi-channel embodiment of the hybrid wireless link of the present invention;

FIG. 3(a) is a block diagram showing the general form of the controller of the hybrid wireless link of the present invention;

FIG. 3(b) is a block diagram showing an example of the controller of the hybrid wireless link of the present invention adapted to function as a binary switch;

FIG. 3(c) is a block diagram showing an example of the controller of the hybrid wireless link of the present invention adapted for multi-channel use with either sub-carrier modulation or wavelength division modulation;

FIG. 3(d) is a block diagram showing an example of the controller of the hybrid wireless link of the present invention adapted for use with a series of latches and a logic unit to allow partitioning for various combinations of signal transmission capacity between the laser portion and the radio frequency portion;

FIG. 4 is an illustration showing an embodiment of the present invention used as a tandem link for extending network reach and used in conjunction with a reflector (mirror) for projecting around a building;

FIG. 5(a) is an illustration showing a typical solution to the breaking of a link in a ring closure with a wireless interconnection to bridge a link in a ring-type network; and

FIG. 5(b) is an illustration showing the use of the hybrid wireless link of the present invention as an improved solution to the breaking of a link in a ring-type network.

DETAILED DESCRIPTION

The present invention provides a method and apparatus that incorporates a wireless optical link and a radio frequency link to provide redundant and backup support for a communication system. The invention assists in overcoming the specific limitations of individual wireless optical and radio frequency links by providing a hybrid link in order to increase communication connectivity and reliability. The following description, taken

in conjunction with the referenced drawings, is presented to enable one of ordinary skill in the art to make and use the invention and to incorporate it in the context of particular applications. Various modifications, as well as a variety of uses in different applications, will be readily apparent to those skilled in the art, and the general principles defined herein may be applied to a wide range of embodiments. Thus, the present invention is not intended to be limited to the embodiments presented, but is to be accorded the widest scope consistent with the principles and novel features disclosed herein. Furthermore it should be noted that unless explicitly stated otherwise, the figures included herein are illustrated diagrammatically and without any specific scale, as they are provided as qualitative illustrations of the concept of the present invention.

The following terms are used throughout the description, and in some cases in the claims, of the present invention. The glossary below is provided as a guide to assist in providing an effective disclosure regarding the essence of the invention.

<u>Glossary</u>

Node: Nodes, in the context of the present invention, indicate network components, for example, general purpose computers, terminals, routers, etc. that incorporate the hybrid wireless link for use in data communications.

Data Systems: Data systems, in the context of the present invention, are computing systems, storage systems, networks, network components, etc., which provide the data that is transmitted via the hybrid wireless links.

Radio Frequency: Radio frequency, in the context of the present invention, includes the entire spectrum of radio frequency radiation, including millimeter wave, microwave, and other frequencies.

Optical: Optical, in the context of the present invention, includes both visible and invisible light of various wavelengths that can be used to transmit data. In particular, the present invention uses laser links to provide data communications.

Environmental information: Environmental information, in the context of the present invention, indicates any information that may be used to determine whether the controller of the hybrid wireless link should route transmissions through the radio frequency portion or the laser portion. Thus, environmental information, in a broad sense, can be determined by such methods as from look-up tables, forecasts, from weather equipment connected with the controller, or from monitoring the real-time transmit/receive power of the radio frequency and laser portions of the hybrid wireless link.

Introduction

The present invention provides a hybrid radio frequency and optical wireless communication link suitable for wireless access, distribution, and backbone network interconnections. The hybrid solution provides enhanced wireless network reliability and an increased network aggregate capacity under all-weather and diverse atmospheric conditions. Other advantages and capabilities of the hybrid wireless link include higher

channel rates compared with a radio frequency link alone, higher wireless network availability, link failure accommodation, selective traffic routing, and relatively high security links. Several specific embodiments of the present invention are provided as guides to an understanding of particular applications in which it may be used. The basic hybrid link will be discussed incorporating, in a first example, a binary switch, which steps the traffic load from all-radio frequency to all-optical and vice-versa, and in a second example, a gradual stepping mechanism, which steps, incrementally, between an all-radio frequency and all-optical and vice-versa. Next, an embodiment of the hybrid link tailored for multi-channel (multiple user) operation will be described. Then, a discussion of the mechanism that provides for switching and stepping between the optical portion and the radio frequency portion is provided. Finally, the present invention will be discussed in the context of various network architectures including the use of the above protection techniques to close, wirelessly, ring network topologies and as a means for extending the reach of typical radio frequency coverage links.

Basic Hybrid Link

A schematic diagram of an embodiment of the hybrid radio frequency and optical wireless communication link of the present invention is presented in **FIG. 1(a)**. In the figure, two hybrid wireless links **100** are shown in communication, providing a gateway between two wired data systems **102**. Specifically, in **FIG. 1(a)**, the data systems **102** represent backbone fiber networks, although as defined above, the data systems **102** may take the form of any systems or nodes between which wireless communication is desirable. A hybrid wireless link **100** of the present invention includes a laser portion

104, a radio frequency portion **106**, and a controller **108**. The laser portion **104** and the radio frequency portion **106** provide, side-by-side and point-to-point, a free-space optical wireless link and a radio frequency wireless link, respectively.

The laser portion **104** of the hybrid wireless link **100** provides a relatively secure and high bandwidth connection, whereas the radio frequency portion **106** is slower and more susceptible to interference, multipath problems, and interception. However, despite its apparent advantages, the laser portion **104** provides poor performance when the atmosphere is filled with relatively small interfering particles such as water vapor in the case of fog. On the other hand, the laser portion **104** is relatively unaffected by the presence of larger particles such as rain and snow (the effect is dependent on particle size). Conversely, the radio frequency portion **106**, despite its generally lower performance, functions well when relatively small interfering particles are present and poorly when larger particles are present. These characteristics make the laser portion **104** and the radio frequency portions **106** good complements to each other for providing a redundant and weather protective system that is operative over a broad range of atmospheric conditions.

In addition to compensating for differing atmospheric conditions, the hybrid wireless link **100** of the present invention also provides a fail-safe system that is remains effective should either one of the laser portion **104** or the radio frequency portion **106** fail. This redundancy is especially useful for ensuring that critical links in a network remain operative.

It is also important to note that depending on the particular configuration, an individual hybrid wireless link **100** could be configured to transmit only, to receive only, or to both transmit and receive communications to and from another hybrid wireless link **100**.

The controller **108** of the hybrid wireless link **100** may be configured as a binary switch, which allows either the laser portion **104** or the radio frequency portion **106** to be active at a given time, but not both. For example, assuming that the laser portion **104** is transmitting information, and a specific event such as equipment failure in one of the portions or a particular atmospheric condition occurs, the controller **108** could re-route communications through the radio frequency portion **106** to minimize the chance of total failure. On the other hand, the controller **108** could also be configured to provide a gradual stepping between the portions in order to maximize the operating bandwidth of the hybrid wireless link **100**. Because the laser portion **104** provides a much higher rate of communication than the radio frequency portion **106**, it may not be desirable to switch exclusively from the laser portion **104** to the radio frequency portion **106** because of the sharp drop in bandwidth. This is in keeping with the fact that the impact of weather on the laser portion **104** is generally a gradual degradation of the link performance, and the link may still be used with a lower traffic load and a lower operating speed. Therefore, in order to provide the maximum bandwidth possible for a given environmental condition, it is desirable to step incrementally from the laser portion **104** to the radio frequency portion **106**, and vice-versa. For example, in the case of fog, the laser portion **104** loses its effectiveness. However, its level of effectiveness depends on the thickness of the fog.

For low levels of thickness, the laser portion **104** can still transfer data much faster than the radio frequency portion **106**. Therefore, the radio frequency portion **106** can be used as a supplement to the laser portion **104** until the laser portion **104** is no longer able to meet the desired quality of service level. Thus, because of its redundancy, the hybrid wireless link **100** of the present invention is able to maintain much greater bandwidth in adverse conditions than that of a typical individual wireless link.

The controller **108** incorporates environmental information in order to determine whether it should use the laser portion **104**, the radio frequency portion **106**, or a combination of both. The environmental information can be obtained in several ways, including by receiving external weather forecasts and by monitoring power reduction based on feedback from another hybrid wireless link **100**. External environmental information forecasts can be obtained from a previously measured, seasonally averaged, and calibrated look-up table, they can incorporate daily weather condition information, or they can be developed internally through the use of weather measuring instruments attached to the hybrid wireless link **100**. On the other hand, two hybrid wireless links **100** in communication can make deductions regarding the weather by continually monitoring the transfer rate of, errors in, and transmission power received by, each of the laser portion **104** and the radio frequency portion **106**. Based on the characteristics of the communication of a particular portion, a deduction may be made about the environment. For example, since it is known that the laser portion **104** is highly susceptible to fog, while the radio frequency portion **106** is susceptible to rain, if there is a sharp drop in the communication ability of the laser portion **104** with relatively small drop in that of the

radio frequency portion **106**, it may be assumed that fog is in the air, and the communication may be re-routed through the radio frequency portion **106**. As the fog begins to lift, and a greater power level is detected from the laser portion **104**, the controller **108** may begin to route more of the communication through the laser portion **106**. In this example, if the controller **108** is configured as a binary switch, its activation may be conditioned upon a specific environmental threshold.

It is important to note that the two portions may be kept active at all times, even though they are not necessarily both transmitting data. It may be desirable to keep both portions active so that the received power of each may be monitored in order to determine when to begin utilizing them for communications.

In situations where a combination of regular or non-secure transmissions and secure transmissions take place, it may be desirable to have the secured transmissions key sent only via the laser portion **104** because its transmissions are much less prone to interception than those of the radio frequency portion **106**. Thus, during times when the laser portion **104** is inactive, only transmissions of the regular or non-secure type would be allowed, and secure transmissions would either be delayed or transmitted in another secure fashion.

A summary of the different states of a communication link formed by hybrid wireless links **100** of the present invention is shown in **FIG. 1(b)**, with a laser communication link **110** and a radio frequency communications link **112**. The dashed lines represent failed

links and the solid lines represent active or standby links. In the case of a binary controller **108**, there are three possible scenarios. In the first scenario, labeled (i), both the laser portion **104** and the radio frequency portion **106** are active. In this case, although both the laser communication link **110** and the radio frequency communication link **112** are functional, the radio frequency portion **106** is likely to be in a standby state because its transmission rate is very small relative to that of the laser portion **104**. In the second scenario, labeled (ii), the laser portion **104** is inactive, or incapable or transmitting, while the radio frequency portion **106** is active, as would be the case in a heavy fog. In this case, all communication occurs via the radio frequency link **112**. In the third scenario, labeled (iii), as would be the case in rain or snow, the radio frequency portion **106** is inactive and the laser portion **104** is active. The three states of the hybrid wireless links **100** just described represent the three possibilities when a binary controller **108** is used. However, in the case of a gradual stepping mechanism, these states represent extreme possibilities, with actual states typically falling somewhere in between.

Depending on the particular embodiment, hybrid wireless links **100** can also be configured to provide an asymmetric communication service, utilizing, for example, a laser portion **104** to provide higher speed downstream capacity and utilizing a radio frequency portion **106** to provide lower speed upstream capacity, or vice-versa. In particular, embodiments of this sort could be highly suitable for adaptive and negotiated bandwidth in either direction.

Multi-channel Hybrid Wireless Link

The protection and link restoration functional capability of the hybrid wireless link **100** discussed above can easily be expanded to a 1:N protection scheme, where N represents the number of redundancies desired within the system, and to multi-channel communication systems. An example of a multi-channel hybrid wireless link **200** is shown in **FIG. 2**. In this embodiment, a laser portion **104** and a multi-channel radio frequency portion **206** are shown. The radio frequency portion **206** incorporates multiple transmitters and/or receivers, each at a different frequency, configured to operate in multiple bands; non-limiting examples of which include Cellular, PCS, NII, millimeter wave, microwave, etc. A single laser portion **104** can operate to provide collective multi-channel communications. The optical signal, in this case, will carry either multiple sub-carrier modulated (SCM) digital and/or analog channels pairing with their radio frequency counterparts or corresponding wavelength division multiplexed (WDM) channels. The SCM and WDM techniques are well known in the art, and fiber optic components and technologies are available for radio frequency carriers well above the presently operating millimeter wave wireless bands.

In a multi-channel embodiment, the controller **208** may receive environmental information that indicates that there will be a greater effect on certain channels than on others. As a result, the controller **208** can provide a finer level of control over the switching or stepping between the laser portion **104** and the radio frequency portion **206** by transmitting those radio frequency channels likely to be most affected by the environment through the laser portion **104** as an optical signal, or conversely, by

transmitting the optical wavelengths likely to be most affected by the environment through the radio frequency portion **206**. The details of the controller **208** will be provided below.

The Controller: Switching Between the Laser Portion and the Radio Frequency Portion

The controller **108** and **208** may be embodied in many specific ways, including as a simple switch and as a latched system that provides an incremental steping between the laser portion **104** and **204** and the radio frequency portion **106** and **206**. The embodiments of the controller **108** and **208**, presented below are readily adaptable to both single and multi-channel hybrid wireless links. It is important to note, however, that these embodiments are considered to be non-limiting examples of possible configurations for the controller **108** and **208**, as many other possible configurations can readily be derived.

In general, the controller **108** and **208** is configured as shown in **FIG. 3(a)**. The controller **108** and **208** includes a 1x2 switch **300**, which receives a data signal **302** and a threshold reference signal **304**. The data signal **302** includes the data to be transmitted by the hybrid wireless link **100**. The threshold reference signal **304** is used to determine whether to send the signal through the laser portion **104** or the radio frequency portion **106** and **206**, or a combination thereof, and can be generated from weather-related data including from current environmental information, from weather information from look-up tables, or from monitoring the transmission power levels of the laser portion **104** and the radio frequency portion **106** and **206**. The outputs of the switch **300** are attached to

an electro/optical converter **306** connected with the transmission optics **308**, and to an RF modem **310** connected with the radio frequency antenna **312**. It is important to note that although in this case, the data signal **302** is assumed to be an electrical signal, with appropriate converters, the controller **108** and **208** is easily adaptable for receipt of an optical signal.

Multi-channel versions of the controller **108** and **208** can be used with time-division multiplexing, sub-carrier modulation, wavelength division modulation, and other techniques. In particular, with sub-carrier modulation and wavelength division modulation, channel filters or color filters are employed in the assembly and dis-assembly of the signal into its components. The general architecture presented in **FIG. 3(a)** is readily adaptable for to these ends. The switch **300**, can be configured to provide switching on a block basis or on a channel-by-channel basis. Switching on a channel-by-channel basis can help to provide a tighter optimization based on current transmission conditions.

It is important to note that many of the switching functions of the controller **108** and **208** may be implemented using a field programmable gate array (FPGA), which is highly controllable, and which can allow the number of channels to be varied for a given situation. Asynchronous transfer mode (ATM) switching technology may also be employed for this purpose.

In addition to single and multi-channel versions of the controller **108** and **208**, an incremental switch **300** may be employed in order to provide different levels of shifting between the laser portion **104** and the radio frequency portion **106** and **206**. By employing multiple levels, the system is able to optimally conform to varying weather conditions. This version of the controller **108** and **208** employs a multilevel latch system that responds to varying levels of the threshold reference signal **304**. The FPGA generates a component clock signal, and depending on which latch is active, prepares different numbers of sub-channel combination loads for the laser portion and radio frequency portion for transmission. The FPGA or ATM, under control of the latches will generate a combination of laser and radio frequency signals to accommodate a particular set of atmospheric conditions.

Below, three specific examples of embodiments of the controller **108** and **208** will be provided in order to assist in providing a better understanding of its operation. It is important to note that the controller **108** and **208** may be configured in many ways, and is not to be considered limited to the examples provided below.

Controller Example 1:

A component overview of a single channel switch embodiment of the controller **108** and **208** is provided in **FIG. 3(b)**. This controller is tailored for the embodiment of the invention shown in **FIG. 1**, and therefore, is applicable to the controller referenced as **108**. The controller **108** includes a plurality of optical fibers **320** as well as a plurality of wire connections **322**. A gateway portion of the controller **324** is connected with the data

system **102** (as shown in **FIG. 1**) to receive a signal for transmission **326**. The major portion of the signal for transmission **326** is provided to a 1x2 electrical/optical switch **328**, while a small tapped portion **330** of the signal for transmission is provided to a photodiode **332** for conversion to an electrical signal **334**. The electrical signal **334** and a reference signal **336** obtained from weather conditions, measured power, or a look up table are provided to a logical AND gate **338** for comparison. Optionally, this check allows the controller **108** to compare the current transmission power to that required to push the optical signal across to the next hybrid wireless link **100**. Alternatively, it allows the controller **100** to utilize a threshold power level derived from environmental information in order to control whether the laser portion **104** or the radio frequency portion **106** and **206** is employed. If the current transmission power is too small or if the weather exceeds a certain threshold, the electro /optical switch **328** will cause the signal for transmission **326** to go into a second leg of the output fiber **340** en route to a radio frequency modem **342** in preparation for transmission. Otherwise, if the hybrid wireless link's **100** current transmission power is sufficiently above the set threshold/reference level, the signal for transmission **326** will go directly to a laser telescope **344** for transmission.

Controller Example 2:

A first multi-channel embodiment of a controller **208** similar to that shown in **FIG. 3(b)** is provided in **FIG. 3(c)**, with a wavelength division multiplexing portion **350** and a sub-carrier modulation portion **352**. This controller is tailored for the embodiment of the invention shown in **FIG. 2**, and therefore, is applicable to the controller referenced as

208. The controller **208** includes a plurality of optical fibers **320** as well as a plurality of wire connections **322**. A gateway portion of the controller **324** is connected with the data system **102** to receive a signal for transmission **326**. A portion of the signal for transmission **326** is provided to a 1x2 electrical/optical switch **328**, while a small tapped portion of the signal for transmission **330** is provided to a photodiode **332** for conversion to an electrical signal **334**. The electrical signal **334** and a reference signal **336** are provided to a logical AND gate **338** for comparison. Optionally, this check allows the controller **208** to compare the current transmission power to that required to push the optical signal across to the next hybrid wireless link **100**. Alternatively, it allows the controller **208** to utilize a threshold power level derived from environmental information in order to control whether the laser portion **104** or the radio frequency portion **106** and **206** is employed. In the case where the sub-carrier modulation portion **352** is used, if the signal for transmission **326** is provided to the radio frequency portion **206**, the signal for transmission **326** is passed through a photodiode **354** for conversion to an electrical signal **356**. The electrical signal **356** is then passed to a channel filter **358**, where the electrical signal **356** is filtered into a plurality F_n channels **360** en route to a radio frequency modem **342** in preparation for transmission by the radio portion **206**. Using wavelength division modulation, the signal for transmission **326** includes a plurality of wavelength channels, and is passed to the wavelength division modulation portion **350**, wherein a wavelength division demultiplexer **362** is used to break the signal for transmission **326** into the wavelength channels **364**. A plurality of photodiodes **366** are used to convert the wavelength channels **364** into electrical signals **368**, which are then sent to a radio frequency modem **342** in preparation for transmission by the radio portion

206. An opposite system corresponding to the wavelength division modulation portion **350** or the sub-carrier modulation portion **352** is employed in the receiving hybrid wireless link **100**.

Controller Example 3:

A portion of a third embodiment of the controller **108** and **208** is provided in **FIG. 3(d)**, wherein a latch system is employed in order to allow the signal for transmission **326** to be divided between the laser portion **104** and the radio frequency portion **106** and **206** in order to tailor the transmission optimally for particular atmospheric conditions. The portion of the controller **108** and **208** shown demonstrates how the small tapped portion of the signal for transmission **330** can be employed with the reference signal **336** in order to determine the portions of the signal for transmission **326** to be sent through the laser portion **104** and the radio frequency portion **106** and **206**. The portion of the controller **108** and **208** receives a signal for transmission **326** from the gateway of the controller **324**. The tapped portion of the signal for transmission **330** is converted to an electrical signal **334** by a photodiode **332**, and is divided among a plurality L_n of latches **380**, representing N different combinations of laser portion **104** and radio frequency portion **106** and **206** transmissions. Each of the latches **380** is configured to activate for a particular power level of the tapped portion of the signal for transmission **330**. Upon activation, the latch **380** corresponding to the current power level sends a signal to a logic unit **382**, typically an FPGA or ATM unit. The logic unit **382** generates an output signal **384** and a clock signal **386**, which is sent to a multiplexer **388**. This portion of the controller **108** and **208**, via the latching mechanism, controls the portions of the signal for

transmission **326** that are transmitted by the laser portion **104** and the radio frequency portion **106** and **206**.

<u>Tandem Use of the Hybrid Wireless Link and Use in Network Topologies</u>

In addition to use as a protective and redundant system, the hybrid wireless link **100** of the present invention may be used in a manner that provides for an extension of typical radio frequency wireless networks. This embodiment is presented in **FIG. 4**, which shows the hybrid wireless link **100** receiving a signal from a laser link **400**, which acts as a gateway to a backbone network **402** or to other systems such as a building **404**. In many areas, radio frequency links do not have sufficient range to broadcast a signal to areas of interest. In the situation shown in **FIG. 4**, one goal is to transmit a signal from a backbone network **402** to a neighborhood of interest **406** located at a distance not reachable by typical radio frequency signals. The laser portion **408** of the hybrid wireless link **100** is used to send and receive longer-range signals to and from the backbone network **402**, while the radio frequency portion **410** of the hybrid wireless link **100** is used to provide network access to the neighborhood of interest **406**. Multiple antennas can be used by the radio frequency portion **410** to accommodate more users in the neighborhood of interest **406**, as the laser portion **104** supports sufficient bandwidth to accommodate many times the aggregate bandwidth of many antennas. Another advantage of the laser portion **104**, particularly in urban areas, is the ability to use an optical reflector **418** in order to get around buildings and other objects. This is shown in **FIG. 4**, where a reflector **418** is used to reflect a signal from a laser portion **412** to be received by another laser portion **414** in order to be re-broadcast by a radio frequency

portion **416** to illuminate a building that would otherwise be out of range of the origin of the laser signal **400**.

In addition to general use in networks and use as a tandem network component, the hybrid wireless link **100** can be used in support of ring network topologies. Current solutions to link breakages in ring networks require the re-routing of network communications in a u-shape so that the defective link is no longer required. This situation is shown in **FIG. 5(a)**, wherein a link breakage **500** is re-routed at node **502** and node **504**. The hybrid wireless link **100** of the present invention is used as shown in **FIG. 5(b)** in order to close a link breakage between nodes **502** and **504**. The hybrid wireless link **100** thus allows the link breakage **500** to be repaired without re-routing the network communications. In addition to use in repairing link breakages **500**, the hybrid wireless link **100** may also be used to branch out from a ring network.